



*Idaho National Engineering and Environmental Laboratory*

# **Absorption of CO<sub>2</sub> by Aqueous Diethanolamine Solutions in a Vortex Tube Gas-Liquid Contactor and Separator**

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May 6, 2003

*Supported by U.S. DOE (DE-AC07-99ID13727)*

# **Project Objectives:**

- ***Low capital cost due to compact, simple design***
- ***High CO<sub>2</sub> capture efficiency***
  - ***high efficiency mass transfer***
  - ***reduced solvent regeneration requirements***
- ***Operationally flexible***
  - ***turn-down & scale-up with parallel design***
  - ***easily accommodates variable flow rates and gas compositions***
  - ***low maintenance/portable configuration***
- ***Works equally well for physical / chemical absorbents***

# **Jet type absorbers highly efficient**

## High Shear Jet Absorber

- *highly turbulent... large interfacial area for mass transfer*
- *multiple jets... impingement zone creates secondary drop breakup / greater area for mass transfer*

Reactor Type	$k_L a$ ( s-1 x 100)
Packed tower	7
Sieve plate	40
Venturi reactor	25
Bubble column	24
<b>Impinging jet</b>	<b>122</b>

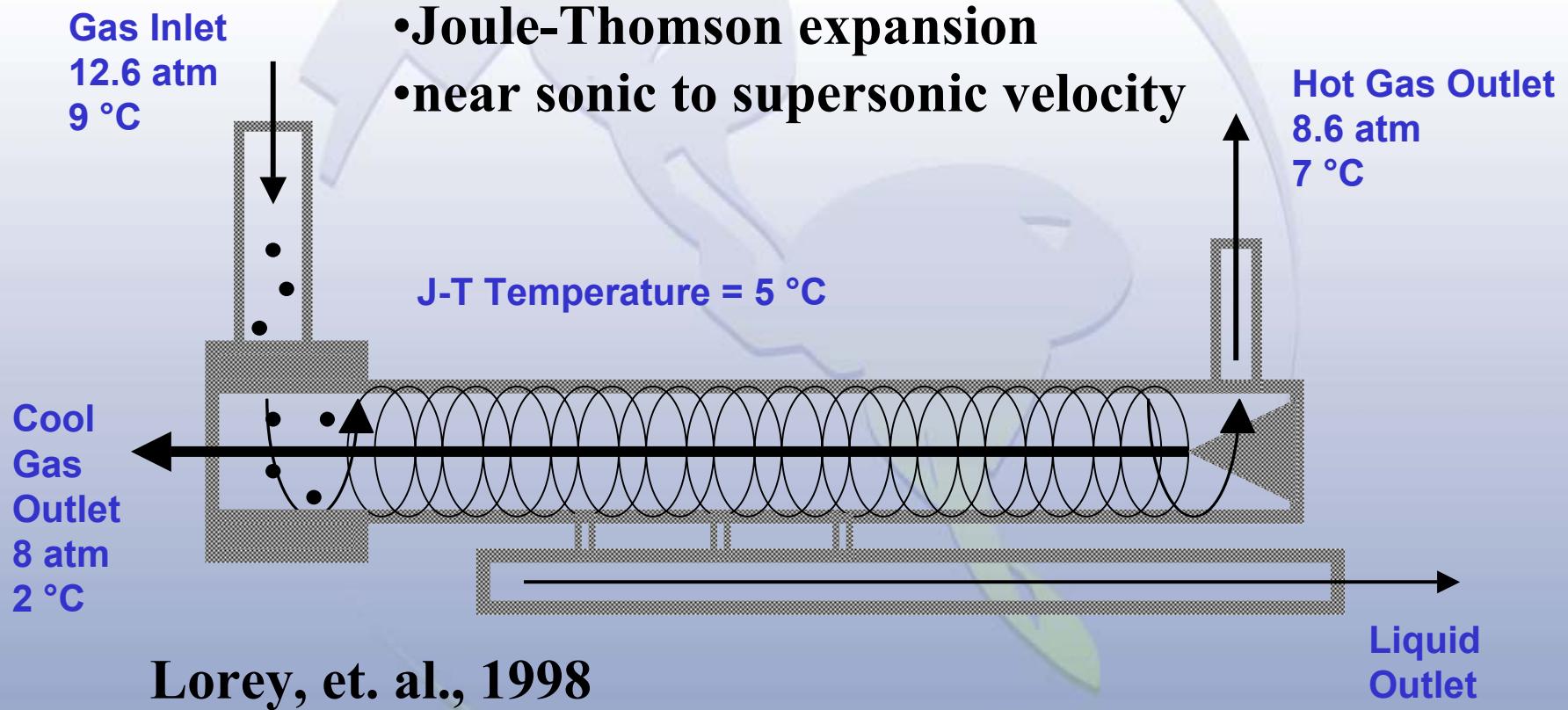
*(Herskowitz et. al.)*

# ***High Efficiency Absorption***

## ***.... acid gas separation***

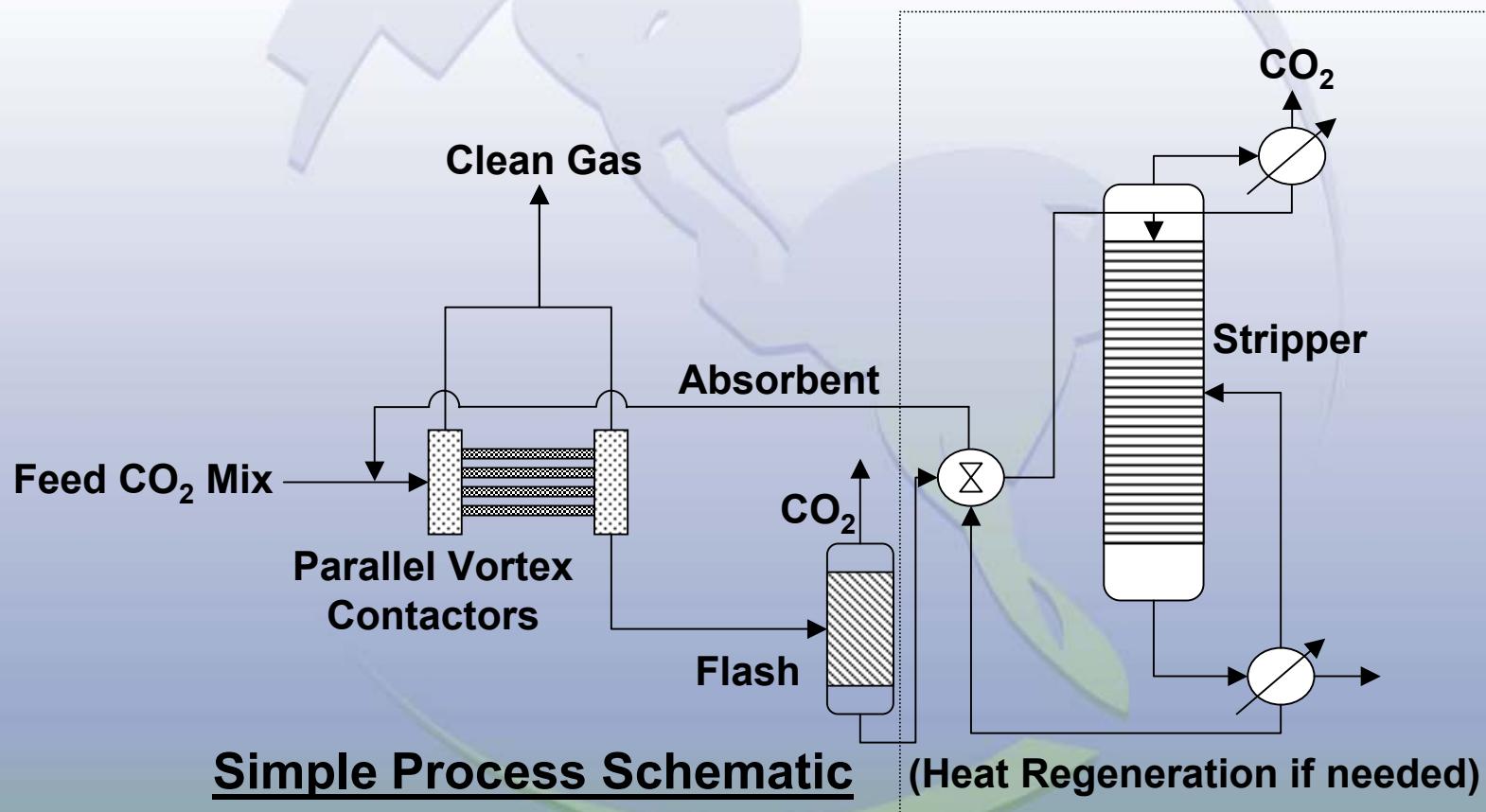
- *Co-inject chemical or physical absorbent*
  - $\text{CO}_2 + 2R_2\text{NH} \leftrightarrow R_2\text{NCOO}^- + R_2\text{NH}_2^+$
  - $R_2\text{NCOO}^- + \text{H}_2\text{O} \leftrightarrow R_2\text{NH} + \text{HCO}_3^-$
  - *R designates  $-\text{C}_2\text{H}_4\text{-OH}$*
- *Mass transfer rate  $\sim f(\text{interfacial area, film thickness})$*
- *Vortex tube*
  - *high differential gas-liquid acceleration - small drops*
  - *high turbulence - small film thickness*
- *GOAL ... achieve near equilibrium acid gas loading*

# Vortex Tube with Liquid Separator



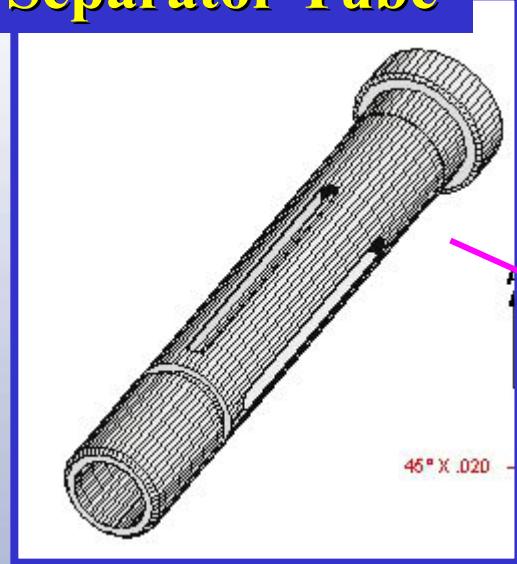
# Scaled Contactor Process

- wellhead (~Mscfd) to full gas plant (~MMscfd)
- distributed engine (~Mscfd) to centralized power plant (~MMscfd)

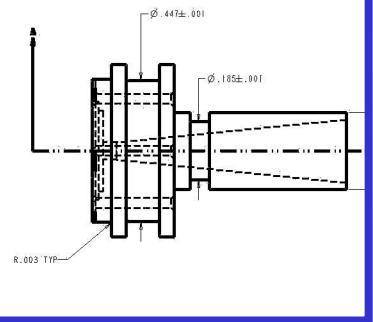
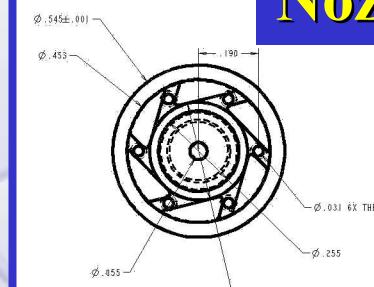


# Vortex Contactor

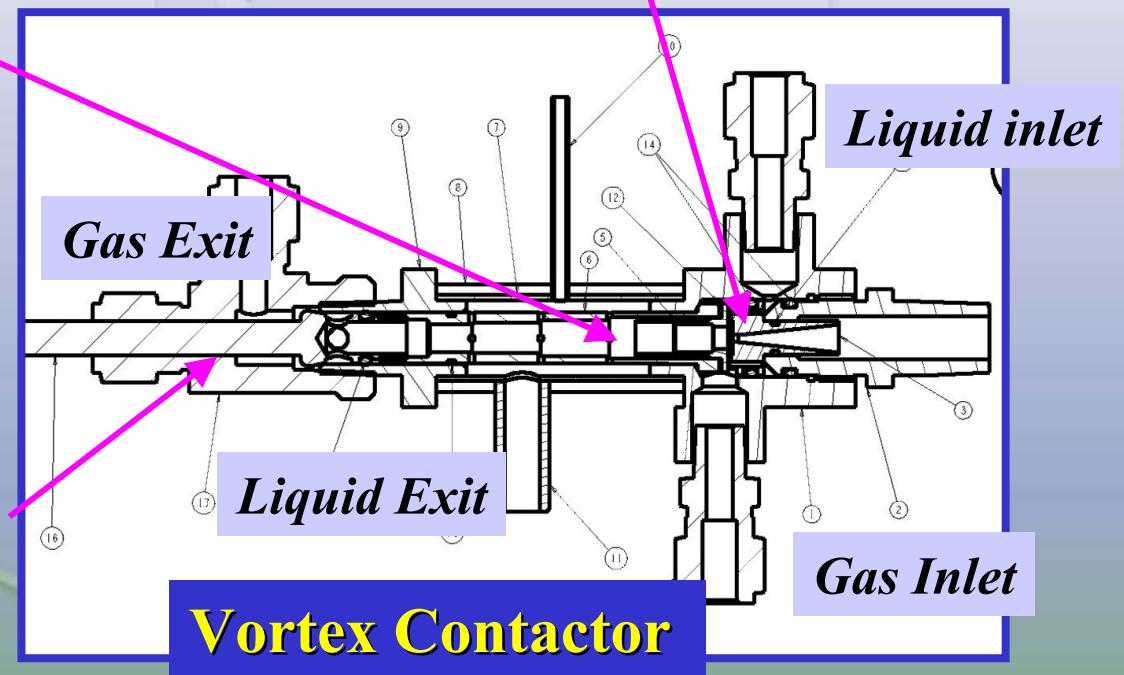
**Separator Tube**



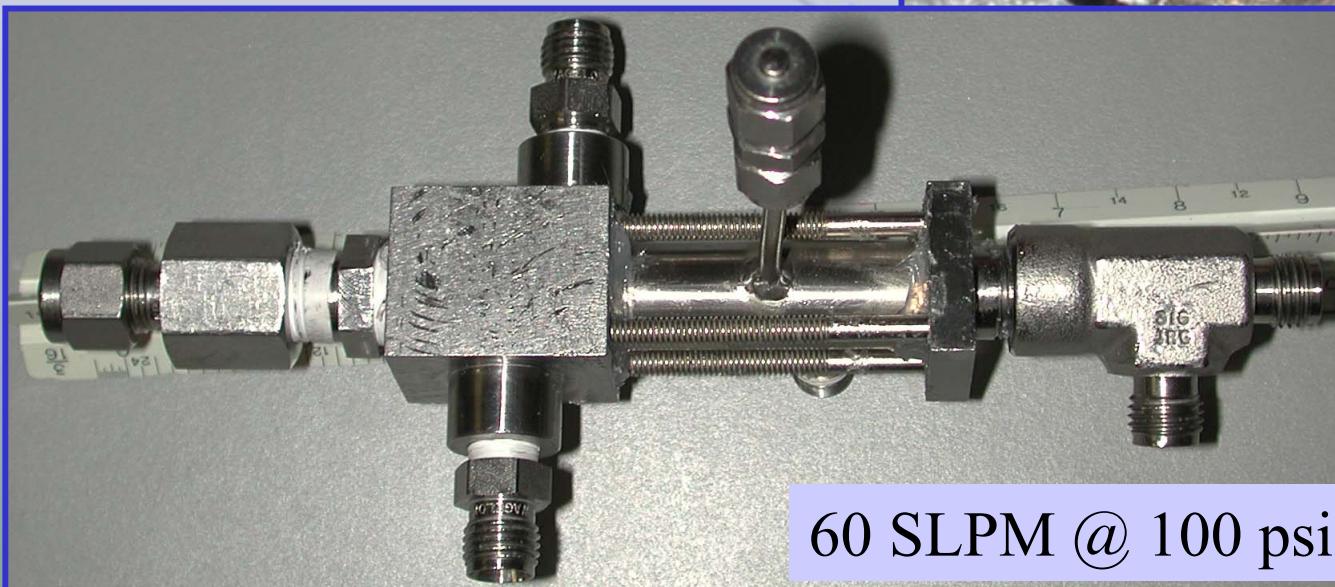
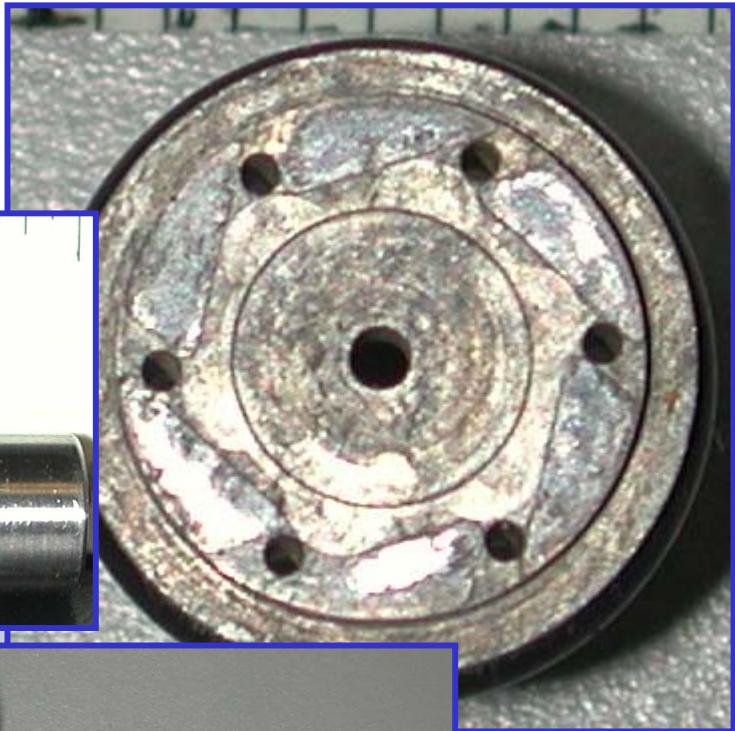
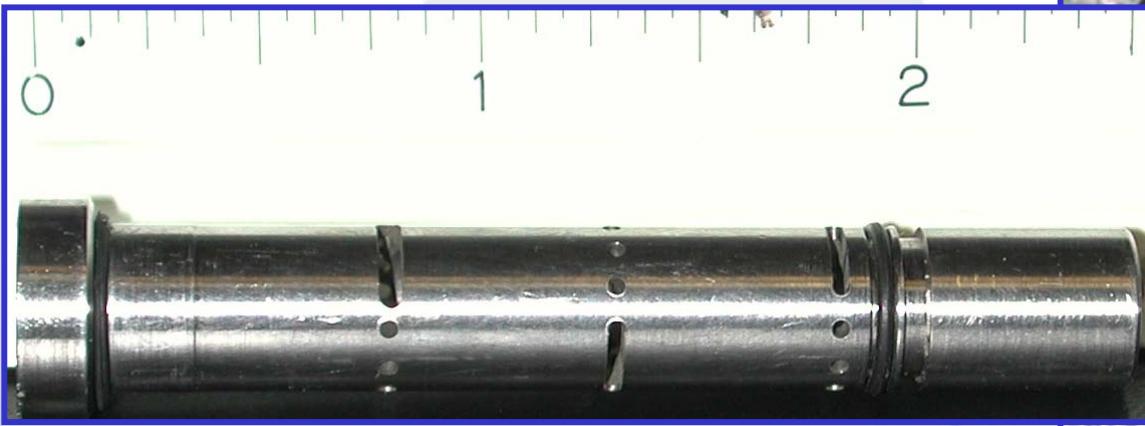
**Nozzle**



**Boroscope / Throttle**



# **Contactor Prototype**

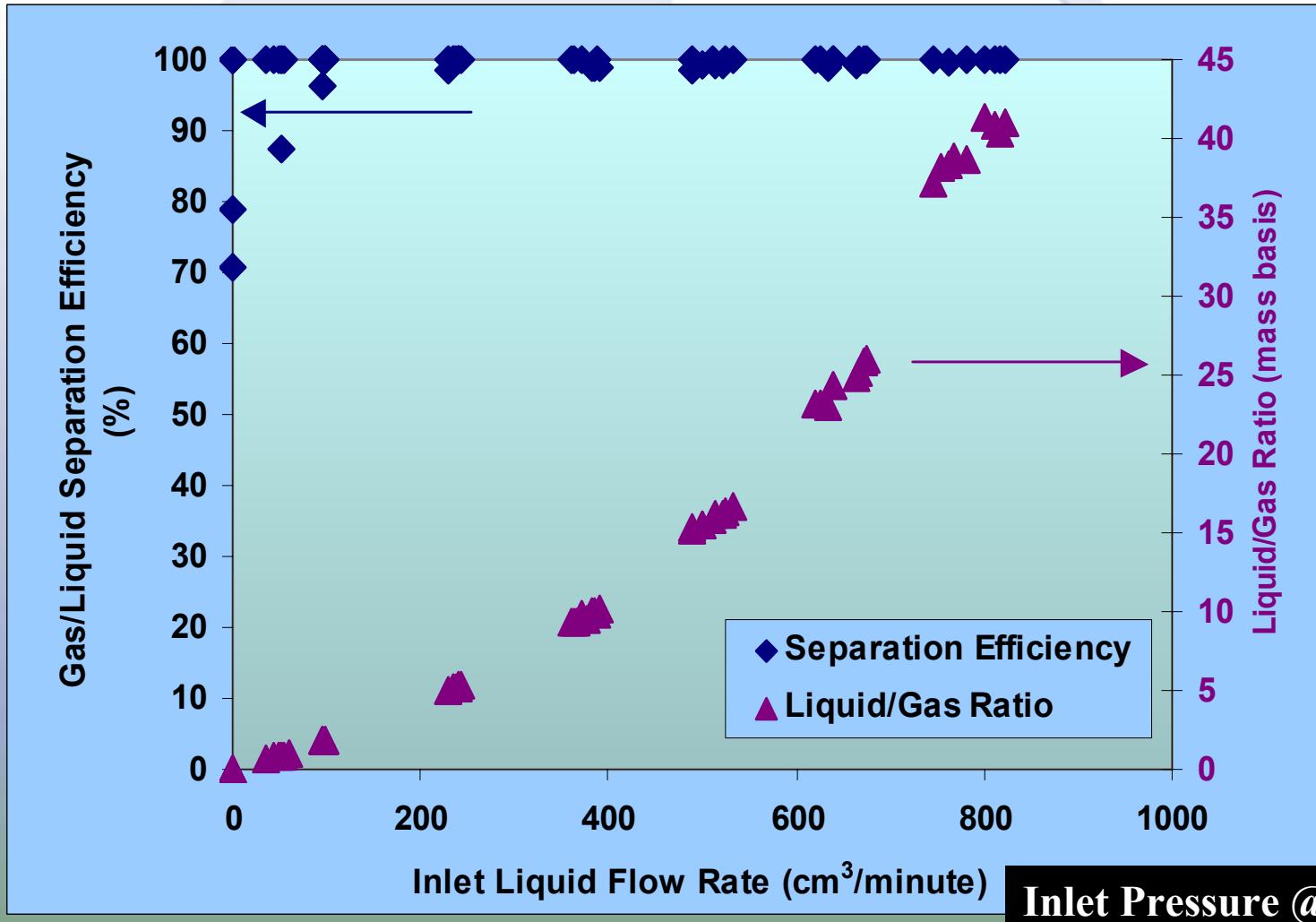


**60 SLPM @ 100 psia inlet**

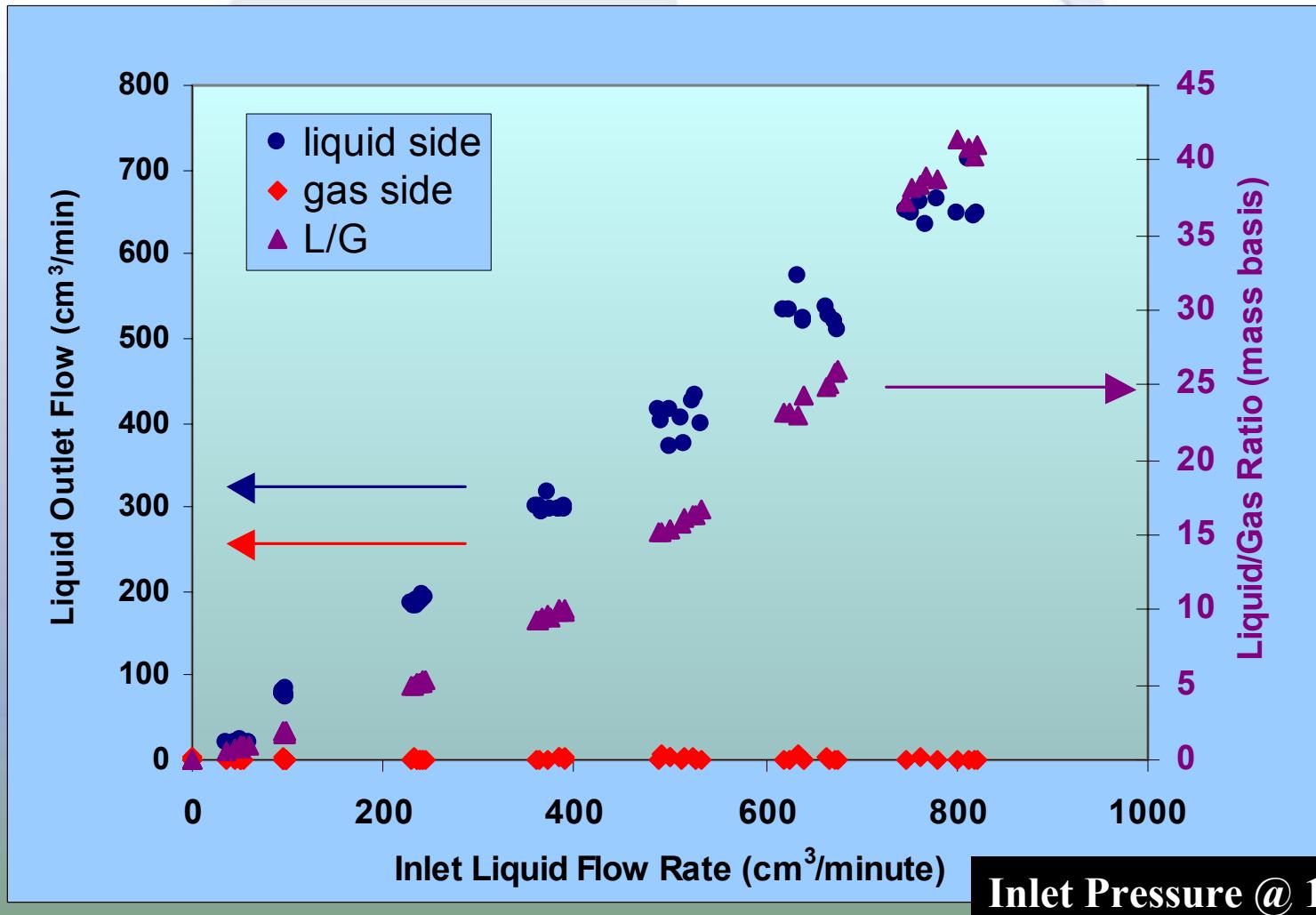
# **Gas - Liquid Loading Tests**

- **Achieve >95% gas-liquid separation for stoichiometric loading of a 15% volume CO<sub>2</sub> mixture**
- **Design parameters**
  - **vortex inlet**
  - **tube design**
    - **tapered & slotted**
    - **stepped with holes**
  - **tube length**

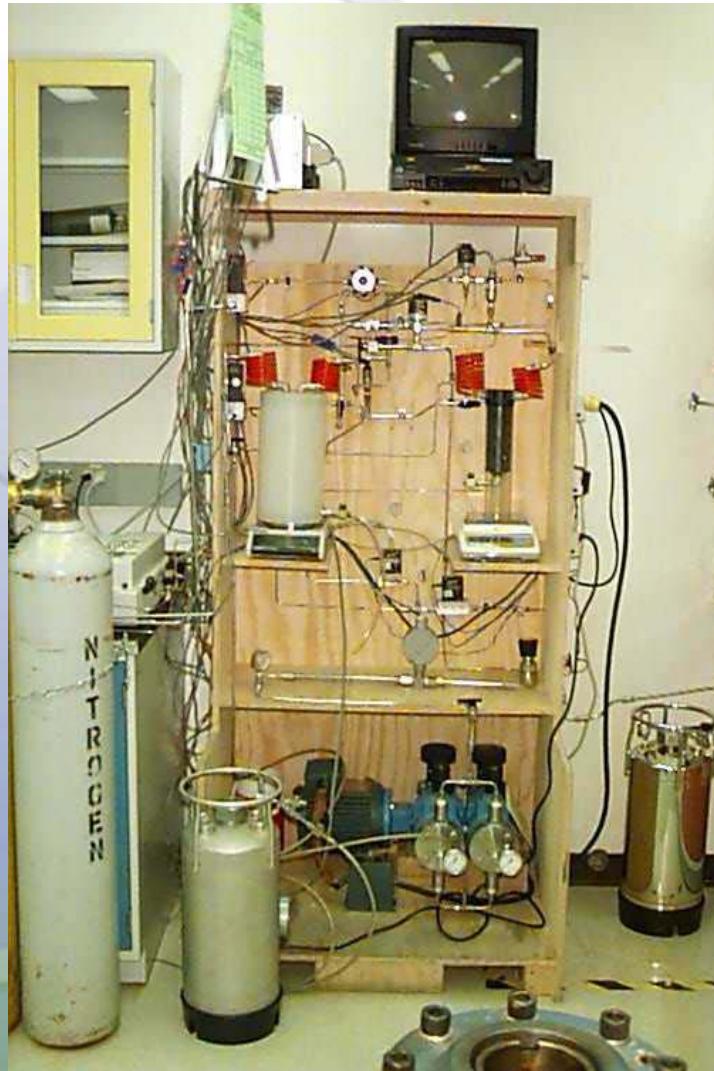
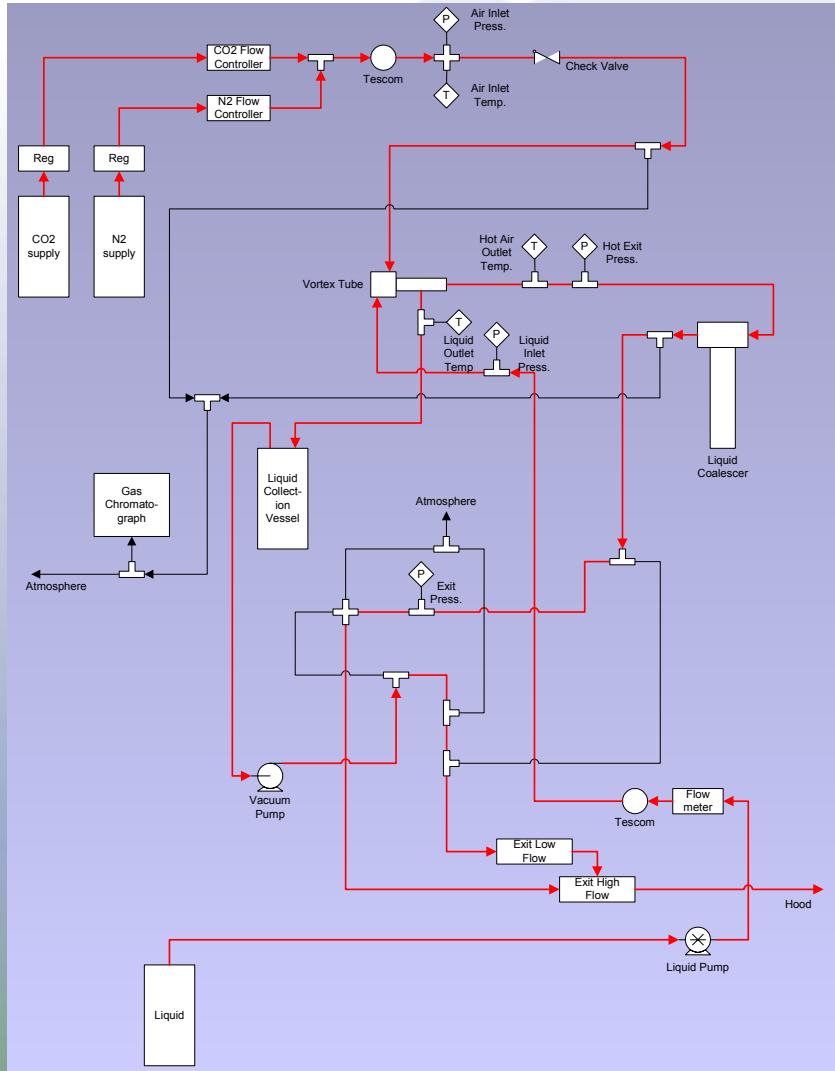
# *Stepped tube design exceeds gas/liquid separation target*



# *Stepped tube design exceeds gas/liquid separation target*



# CO<sub>2</sub>/DEA Baseline Test Apparatus



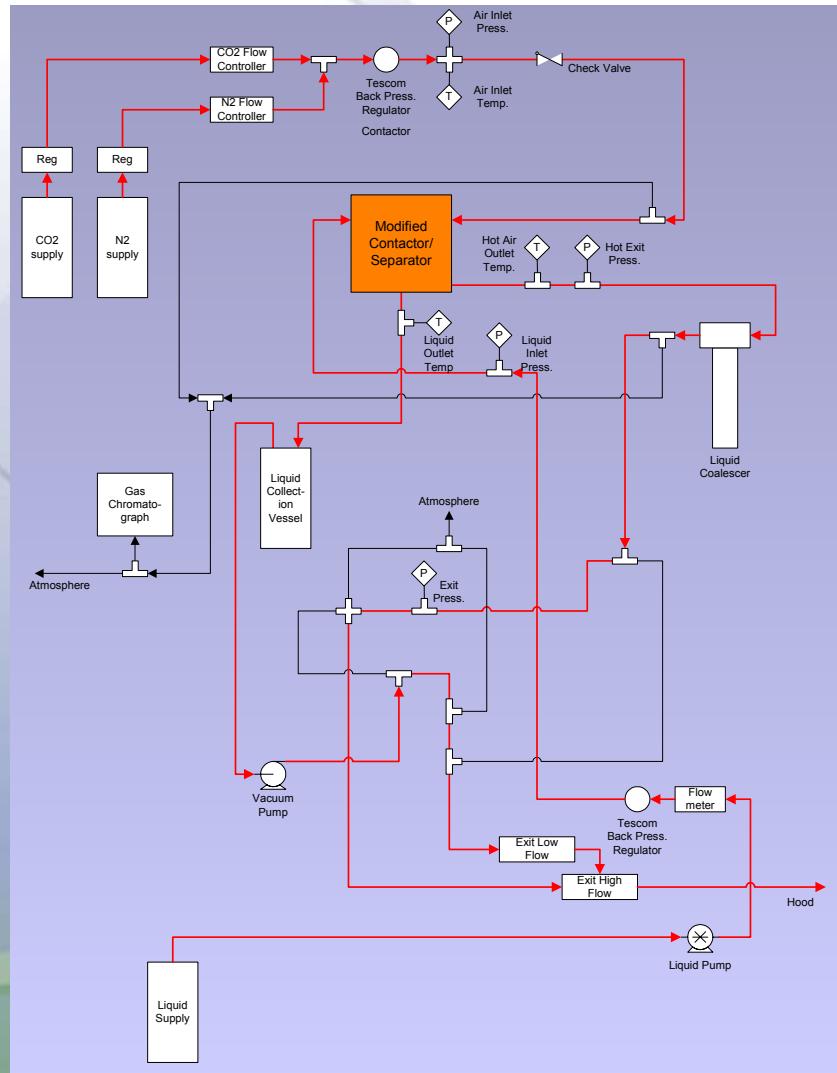
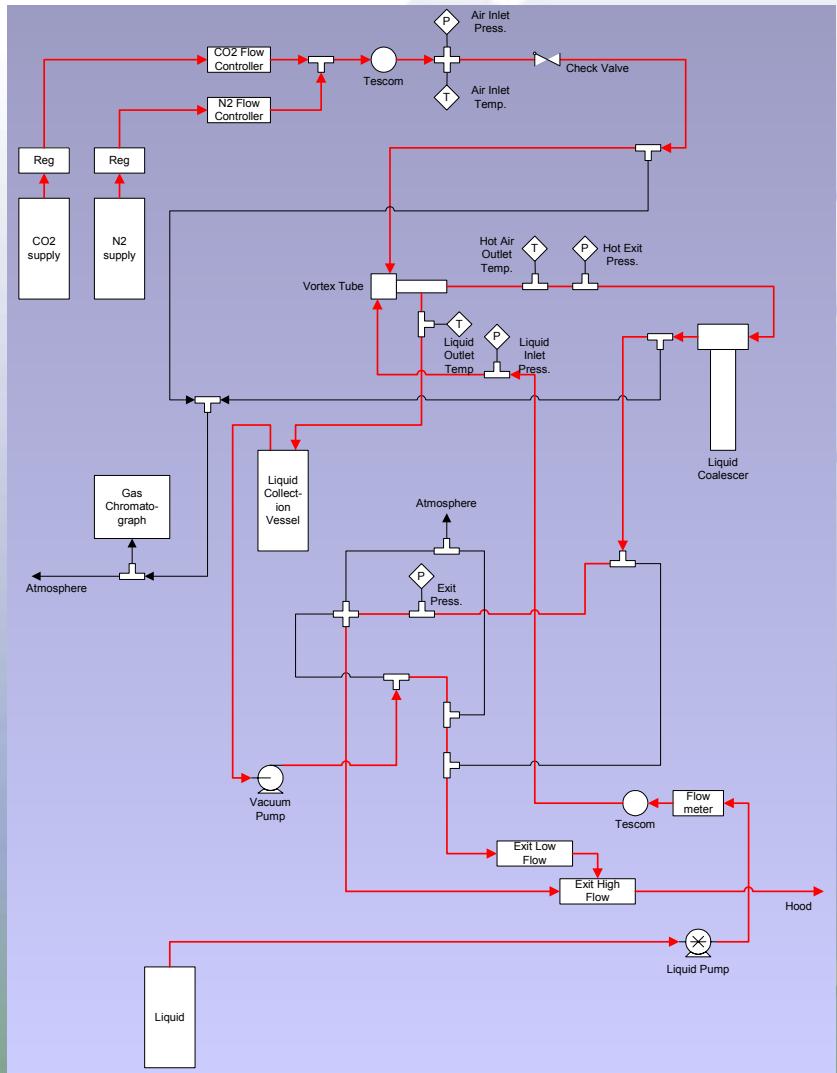
# **CO<sub>2</sub>/DEA Baseline Testing Operation**

- *Operating Parameters*
  - 100-500 cm<sup>3</sup>/min liquid flow rate
  - 15-50 wt% liquid DEA composition
  - 80-200 psig inlet gas pressure
  - 5-15 mol% inlet gas CO<sub>2</sub> composition
  - 25-75 slpm inlet gas flow rate (*dependent variable*)
- *Solvent loading and CO<sub>2</sub> capture efficiency unsatisfactory in baseline testing*
- *Diagnostic testing indicated increased residence time required – process modifications necessary*

# **Process Modifications**

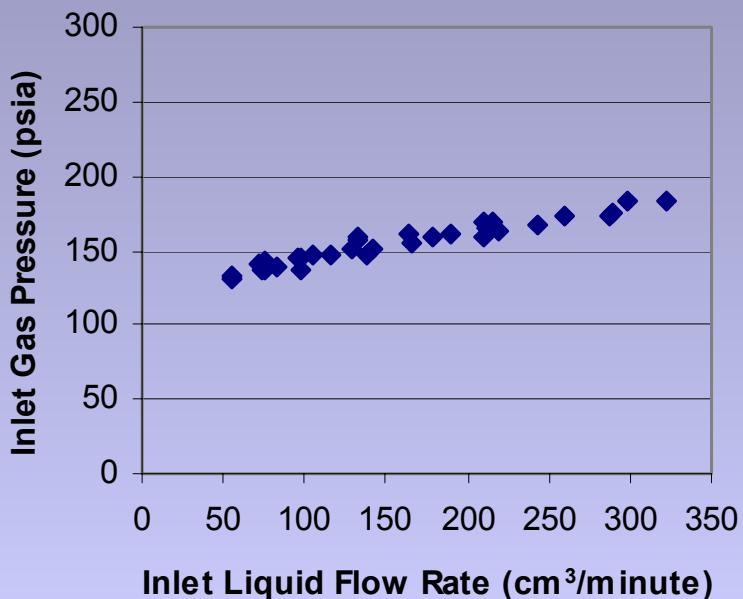
- *Modifications to process hardware*
  - increase gas-liquid contact time
  - capacity to adjust the gas-liquid contactor geometric configuration
  - maintain ability to control the inlet gas pressure and CO<sub>2</sub> : DEA feed stream mole ratio
- *Modifications to process operating parameters*
  - 75-350 cm<sup>3</sup>/min liquid flow rate
  - 30 wt% liquid DEA composition
  - 70 slpm inlet gas flow rate
  - 10 mol% inlet gas CO<sub>2</sub> composition
  - 170-250 psig inlet gas pressure (dependent variable)

# Baseline and Modified Process Configurations

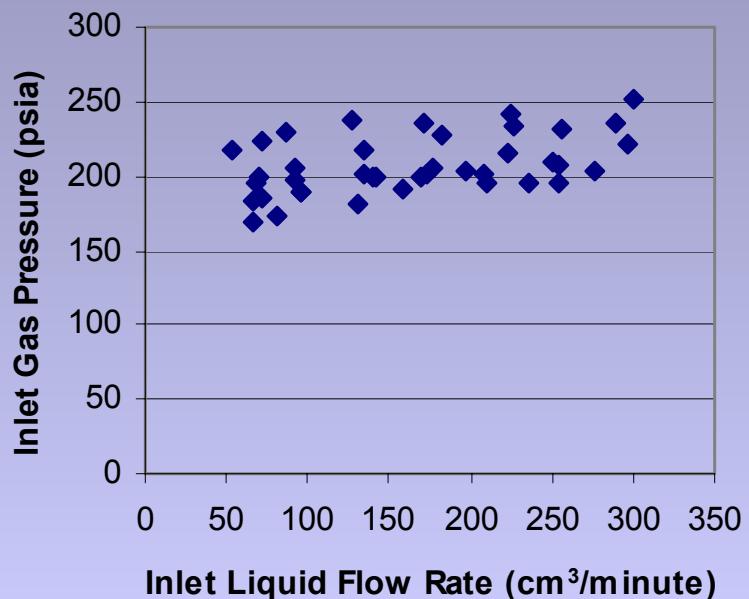


# **Inlet gas pressure as a function of liquid flow rate**

Fouling is caused by deposits accumulating in the vortex tube nozzles

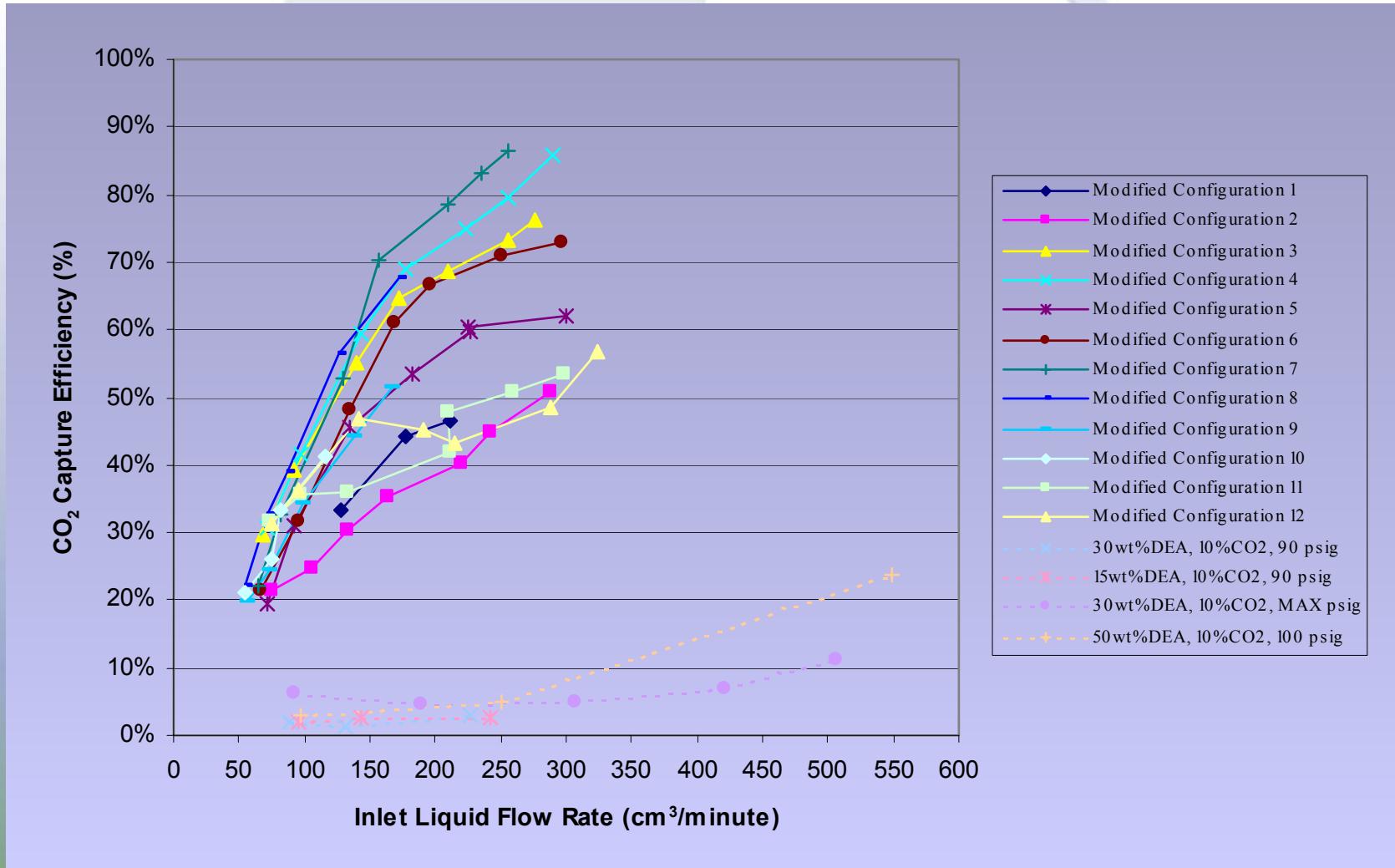


No Nozzle Fouling

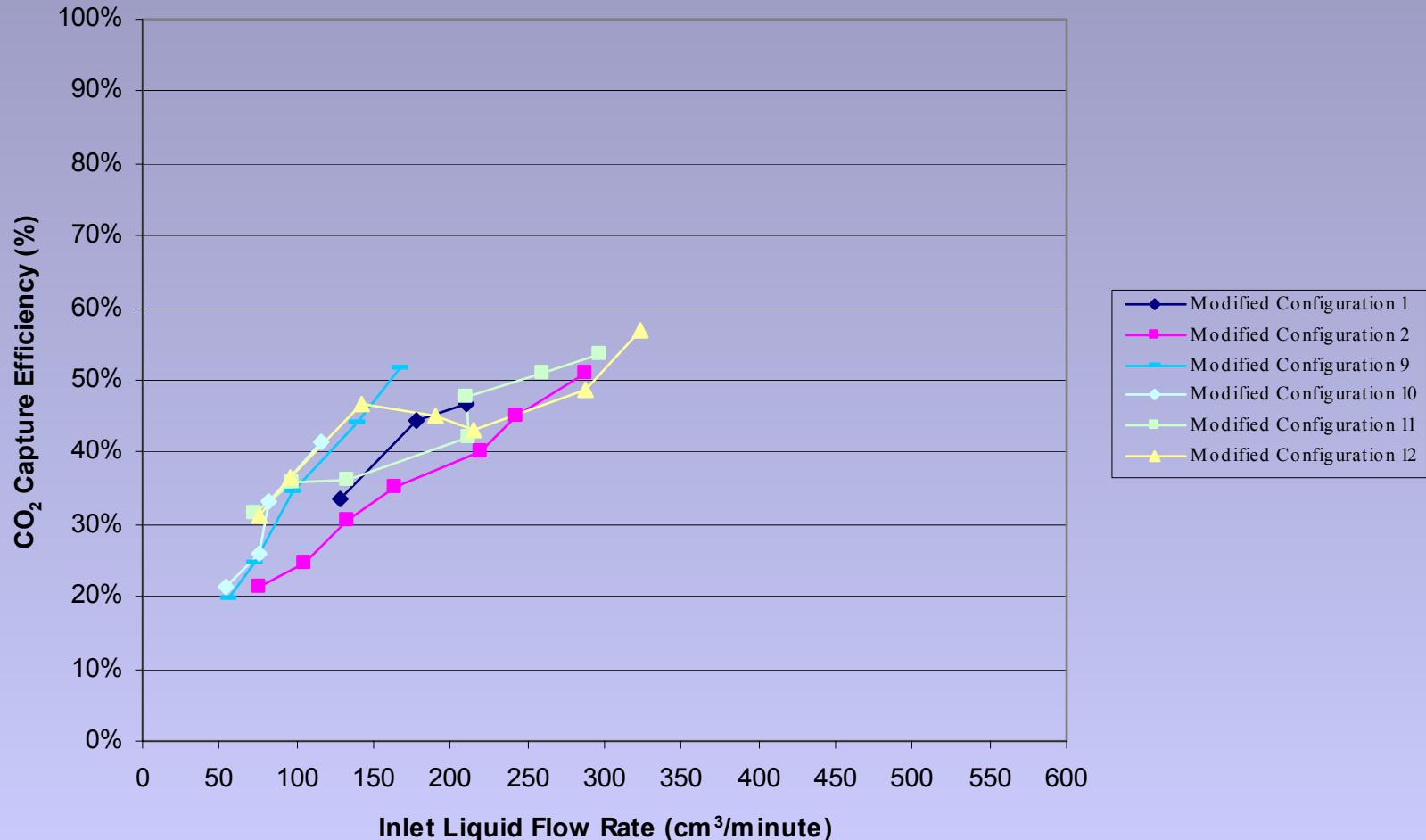


Nozzle Fouling Present

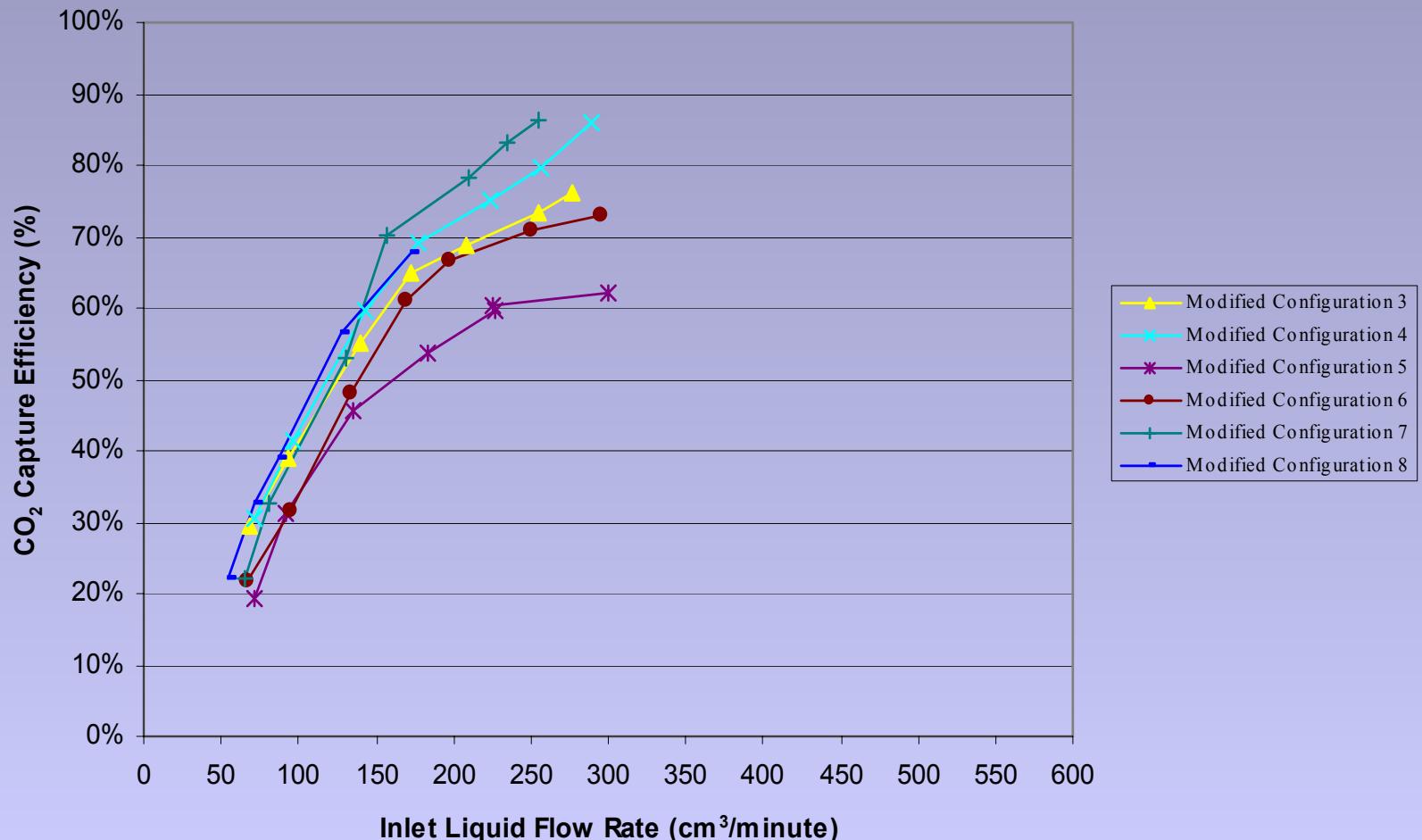
# *CO<sub>2</sub> capture efficiency as function of liquid flow rate*



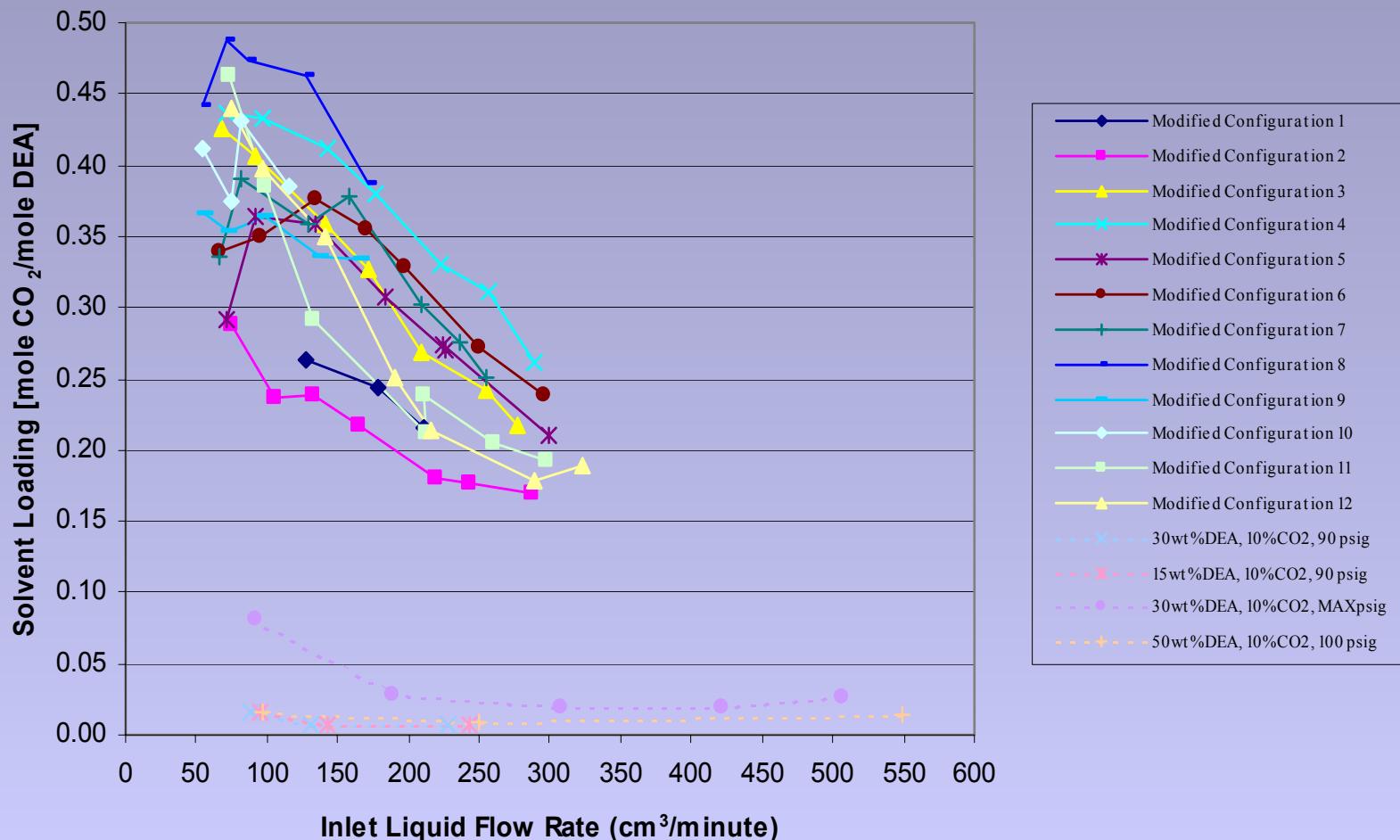
# ***CO<sub>2</sub> capture efficiency as function of liquid flow rate (no fouling)***



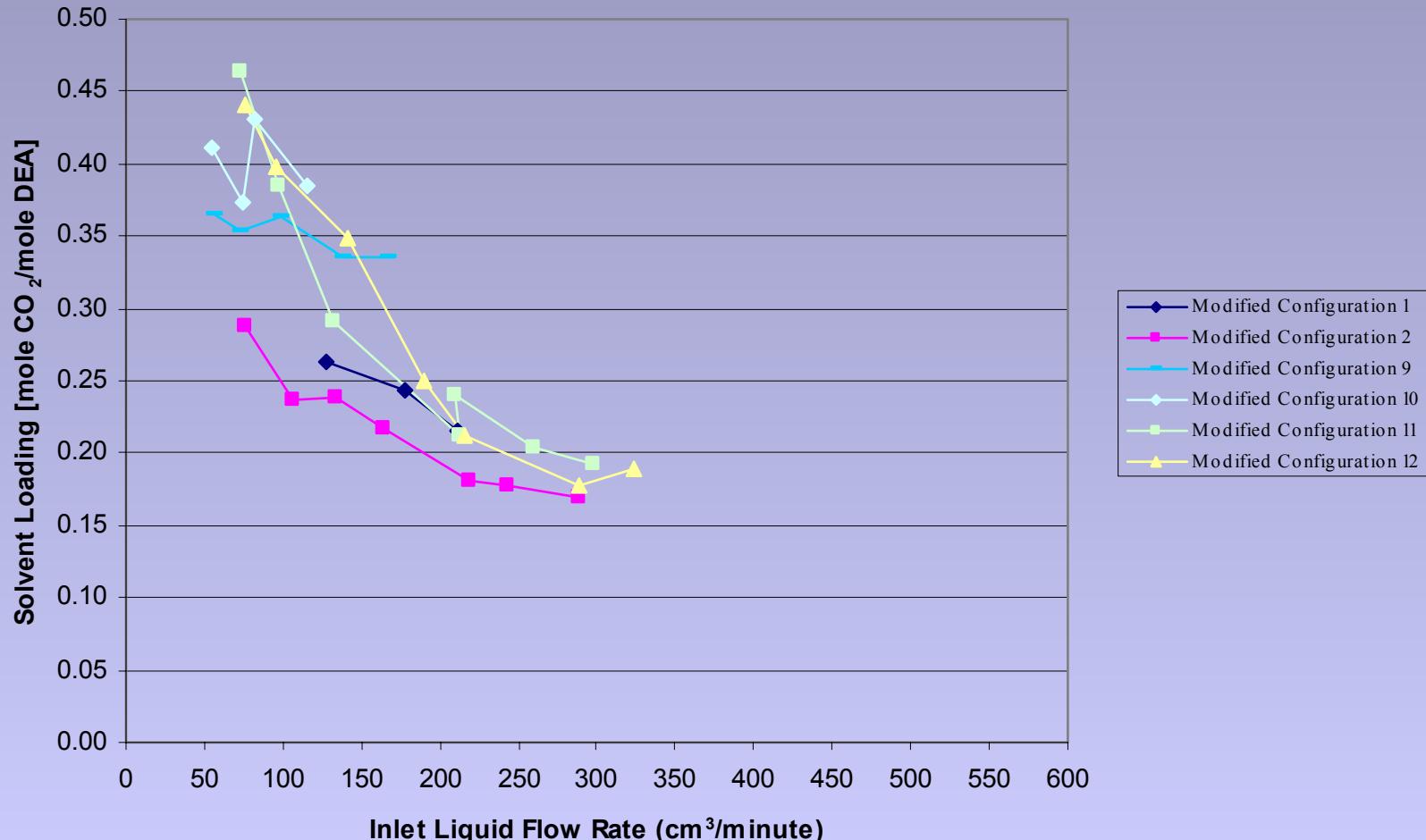
# ***CO<sub>2</sub> capture efficiency as function of liquid flow rate (fouling present)***



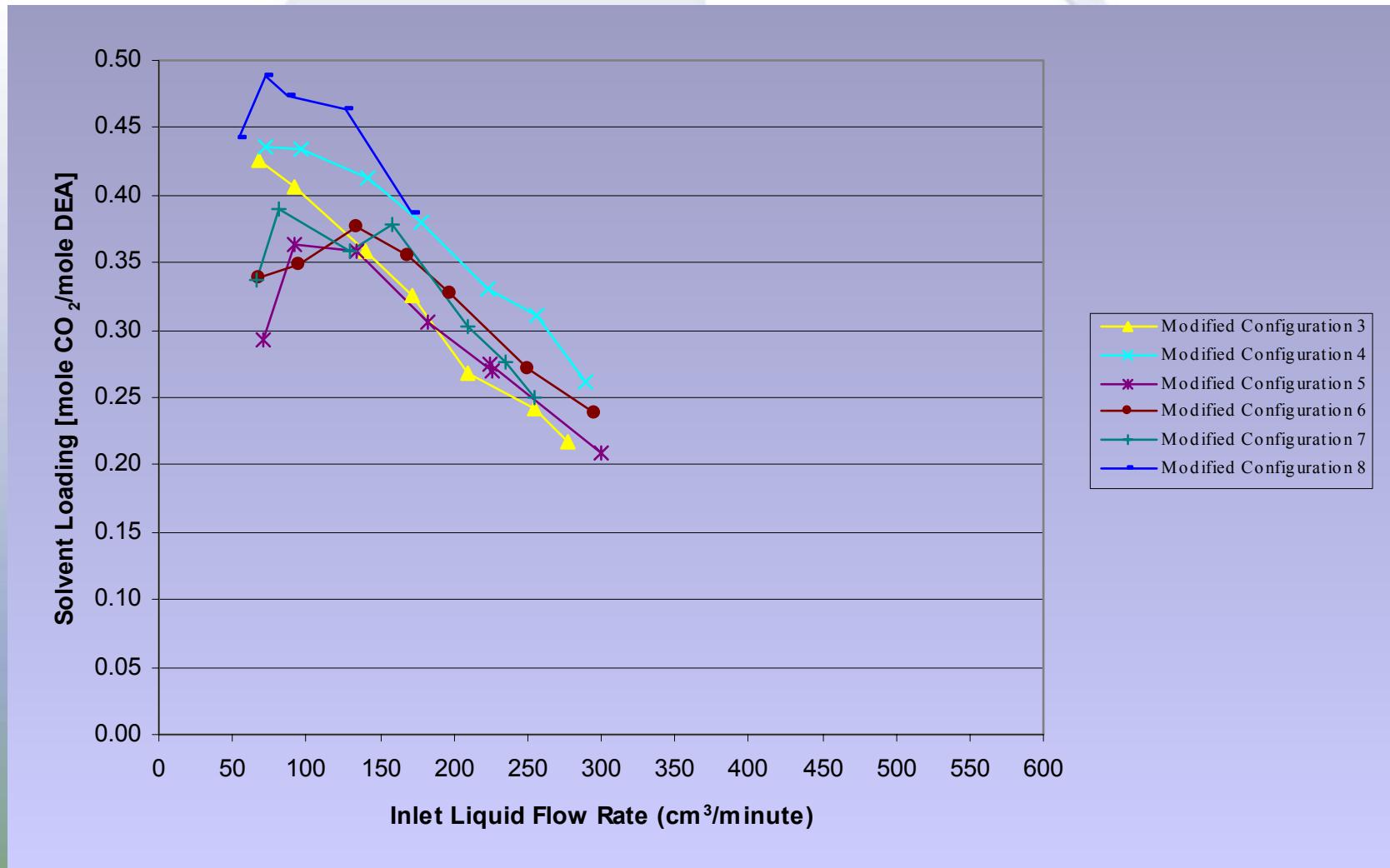
# *Solvent loading as function of liquid flow rate*



# **Solvent loading as function of liquid flow rate (no fouling)**



# Solvent loading as function of liquid flow rate (fouling present)



# Conclusions

- *Gas/Liquid separation efficiencies in excess of 95%*
- *Non-optimized vortex tube testing has resulted in carbon dioxide capture efficiencies of up to 86%*
- *Solvent loading as high as 0.49 moles CO<sub>2</sub>/mole DEA*

# *Future Research/Applications*

- *Process hardware optimization*
- *Scaled contactor and separator*
- *Additional solvents*
- *Additional CO<sub>2</sub> applications*
- *H<sub>2</sub>S*

# References

- Herskowitz, D.; Herskowitz, V.; Stephan, K.; Tamir, A.: *Characterization of a two-phase impinging jet absorber. II. Absorption with chemical reaction of CO<sub>2</sub> in NaOH solutions.* Chem. Eng. Science 45 (1990) 1281-1287
- Lorey, M., Steinle, J., Thomas, K. 1998. "Industrial Application of Vortex Tube Separation Technology Utilizing the Ranque-Hilsch Effect," presented at the 1998 SPE European Petroleum Conference, The Hague, Netherlands, October 20-22.
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- Lee, J. I., Otto, F. D., and Mather, A. E., "Solubility of Carbon Dioxide in Aqueous Diethanolamine Solutions at High Pressures", Journal of Chemical and Engineering Data, Vol. 17, No. 4, 1972.